Ekonomika i Organizacja Logistyki
1 (4), 2016, 51–59

Borut Jereb, Samo Kumperščak, Tadej Bratina
University of Maribor

Green wave in urban traffic

Zielona fala w miejskim ruchu drogowym

Abstract. Over 70% of the European population lives in urban areas. This puts pressure on urban transport systems, leading to increased environmental impacts. Such impacts are particularly large in cases where the traffic caused by vehicles with internal combustion engines is repeatedly braking and accelerating due to poorly planned traffic flow. We do not know exactly how much of the pollution is increased by braking and accelerating vehicles at traffic lights; on the other hand, we can evaluate the contribution of higher fuel consumption. We have evaluated such an increase in fuel consumption in the real case of a road section in Celje. Based on the obtained results, we are able to estimate the factor of pollution increasing caused by accelerating. By adding the estimates of pollution caused by braking, we get an overall picture of the importance of ensuring a steady flow of traffic to reduce pollution in urban environments.

Key words: urban traffic flow, air pollution, PM_x particles, increased fuel consumption, green wave

Synopsis. Ponad 70% mieszkanców Europy żyje na terenach zurbanizowanych. Powoduje to duży nacisk na właściwe funkcjonowanie miejskich systemów transportowych, co prowadzi do negatywnego wpływu na środowisko naturalne. Wpływ ten jest tym większy, gdy w miastach ruch drogowy jest regulowany w sposób mało płynny. Nie wiadomo dokładnie, jak duży udział w generowaniu zanieczyszczeń powietrza ma zbyt częste hamowanie i przyspieszanie pojazdów na sygnalizacji świetlnej, ale możliwe jest oszacowanie wpływu takich manewrów na poziom zużycia paliw. Autorzy oszacowali taki wpływ, przeprowadzając badania na drogach miasta Celje. Bazując na uzyskanych wynikach, oszacowano wpływ nadmiernej liczby przyspieszeń w ruchu drogowym na poziom zanieczyszczeń powietrza. Dodając do tego wyniki zanieczyszczeń generowanych podczas hamowania pojazdów, uzyskano odpowiedź na pytanie: jak duży wpływ na poziom zanieczyszczeń w mieście ma brak płynności ruchu i jak go zmniejszyć.

Słowa kluczowe: miejski ruch uliczny, zanieczyszczenie powietrza, cząsteczki PM, zwiększone zużycie paliwa, zielona fala

Introduction

With our research paper, we tried to discover how traffic lights regime and so-called green wave influences fuel consumption and pollution, which is bad for our health and also has bad influence on our planet and nature. Research was done in the case of

Mariborska cesta in Celje, for which we gathered all necessary data that was later used in our calculations. There is 14 traffic lights on our research area. We were calculating differences in fuel consumption between green wave and worse scenarios of traffic regime (from 1 stop to 14 stops). Data, which were used in our calculations, were gathered from different vehicle owners and with our measurements. We took into account only acceleration, but we did not include braking. However, results show important difference in fuel consumption and consequently in pollution. We focused only on petrol and diesel, because there is such a small percentage of other alternative propellants.

Our research paper is important, because it shows differences between green wave and other worse scenarios or traffic lights regimes. It has a huge impact on fuel consumption and consequently on emissions, which are bad for people, animals, nature and it also costs our healthcare system a lot of money. Importance of green wave, which was discussed in other researches, is substantiated with actual results in different situations on Mariborska cesta in Celje. Even results from such a small area (3,202 m) show huge differences in fuel consumption and based on them, we can deduce that it has strong contribution to global pollution.

In our research, we tried to gather as much data as possible for Mariborska cesta and different categories of vehicles. All of the data is average, because we want realistic results and conclusions, which do not rely on single category or type of vehicle, but focus on whole.

Purpose and research methodology

Determining and measuring time for each category of vehicles

Before we could calculate acceleration and distance, we had to find out how much time is needed, for different categories of vehicles, to accelerate from 0 to 50 km/h. We used average time for each category.

Cars. Time (t) that car needs to accelerate from 0 to 50 km/h was measured with stopwatch. Data for cars was gathered for seven average cars, which were different by shape, fuel type and type of engine. We drove cars with engines on petrol and diesel fuel, but we did not include other types of fuel, because there is such a small percentage of alternative fuel and electric cars in Slovenia (around 0.8% of all alternative types) and it does not importantly effect our end results [Statistični urad Republike Slovenije 2016]. We also drove our test cars for some time, because we wanted to determine realistic or average level of acceleration, which is similar to real conditions. We timed every car for three times and calculated average time for whole category from our results. With this average time, we were able to calculate acceleration and distance, which is needed for car to accelerate from 0 to 50 km/h. Average time for category "cars" is 10.4 s.

Buses. Time (t) that bus needs to accelerate from 0 to 50 km/h, was determined after interviews and consultations with bus drivers. We had to take into account difference in driving style between city bus and regional bus, because people stand and sit on city buses and driver has to take that into a count for safety of standing passengers. Acceleration time also depends on time of the day, because there is a lot of congestions in rush-hours and acceleration from 0 to 50 km/h can be as long as 20 s or more. We decided to choose optimal time at normal acceleration of bus, which is 15 s.

Motorcycles. There is a lot of different vehicles in category “Motorcycles” – motorcycles, scooters, three-wheelers and four-wheelers. Because there is only 0.5% of vehicles from category “motorcycles”, it barely effects end results of this research paper [Štetje 2014]. We decided that to use 125 ccm motorcycle (Honda CBF) as a sample in our calculations for this category, because of diversity in this category (accelerations, fuel consumption, shape, chassis). Honda CBF represents average between weak scooters and powerful motorcycles or other types of vehicles in this category. Time (t), that motorcycle needs to accelerate from 0 to 50 km/h, was determined with stopwatch and timing of Honda CBF. We did five measurements and calculated an average of 8.18 s.

Light goods vehicles (below 3.5 t). In this category are light (small) trucks and vans. Time (t), which light goods vehicles need to accelerate from 0 to 50 km/h, was determined after timing and measuring vehicles from Post of Slovenia d.o.o., which belong in this category. We were driven in empty and full vehicles and calculated an average time of 12 s. It has to be taken into account that there is a lot of differences in types of chassis, tonnage, volume, gearboxes (automatic, manual) and engines, which means that there is a lot of differences in measured times.

Medium goods vehicles (3.5–7 t). In this category are trucks with maximum permissible laden weight from 3.5 to 7 t. Time (t), that medium trucks need to accelerate from 0 to 50 km/h, was determined after timing and measuring vehicles from Post of Slovenia d.o.o., which belong in this category. We were driven in empty and full vehicles and calculated an average time of 14 s. Vehicles with automatic gearbox are in general faster that vehicles with manual gearbox.

Heavy goods vehicles (over 7 t). In this category are trucks with maximum permissible laden weight of over 7 t. Time (t), which heavy trucks need to accelerate from 0 to 50 km/h, was determined after timing and measuring vehicles from Post of Slovenia d.o.o., which belong in this category. We were driven in empty and full vehicles and calculated an average time of 16 s. Based on that time we have calculated acceleration and distance. Differences in acceleration between full and empty vehicles are very big in this category and it is the same between vehicles with automatic and manual gearboxes.

Trailer vehicles. Time (t), which trailer vehicles need to accelerate from 0 to 50 km/h, was determined the same way as for towing vehicles, because they weight approximately the same as towing vehicles (full and empty). Employees at Post of Slovenia d.o.o. have also told us that there are no relevant differences between towing vehicles and trucks with trailer. Acceleration time is 18.5 s, the same as for towing vehicles.

Towing vehicle. We received details for towing vehicles from employees in logistics company Ploj d.o.o. Time (t), which towing vehicles need to accelerate from 0 to 50 km/h, was determined after talking to employees and it is 18.5 s. This time represent the average number between acceleration of an empty and full loaded truck, which can weight up to 40 t. Based on that time we have calculated acceleration and distance.

Calculation of acceleration and distance

To do further calculations, we first had to measure and set some presumptions, which were than used. We had to measure and calculate distance, which different categories need for acceleration from 0 to 50 km/h. This calculation was based on time that we measured or set for each category of vehicles. First we calculated acceleration, which was then used in equation (2) for distance.

We divided change of speed (Δv = 50 km/h) with change of time (Δt – time that vehicle needs to accelerate from 0 to 50 km/h), to calculate acceleration. Equation:

$$a = \frac{\Delta v}{\Delta t} \tag{1}$$

Time (t) and acceleration (a) which were measured and calculated, were then used in equation (2) for calculation of distance (s) that vehicle needs to accelerate from 0 to 50 km/h.

$$s = \frac{a \times t^2}{2} \tag{2}$$

Table 1. Average acceleration times up to the desired speed of 50 km/h and distances travelled during acceleration
Tabela 1. Średni czas przyspieszania do prędkości 50 km/h oraz dystans pokonany w tym czasie

Type of vehicle	Average acceleration time from 0 to 50 km/h (s)	Distances travelled during acceleration (m)
Cars	10.4	72
Light goods vehicles (below 3.5 t)	12	83
Medium goods vehicles (3.5–7 t)	14	97
Heavy goods vehicles (over 7 t)	16	111
Trailer vehicles	18.5	128
Towing vehicles	18.5	128
Buses	15	104
Motorcycles	8.2	57

Source: [Kumperščak, Bratina and Jereb 2016].

Fuel consumption during acceleration

Average fuel consumption was calculated on the basis of monitoring the consumption during acceleration via computer in the car, conversations with professional drivers and the assessment of fuel consumption in different enterprises in different driving cycles. It was calculated as a quotient between consumption during acceleration and average fuel consumption.

The quotient is presented by the following formula:

$$\text{factor} = \frac{\text{consumption during acceleration}}{\text{average consumption}} \tag{3}$$

It turns out that practically for all types of vehicles on our roads and in the standard driving mode the factor is 2.65. As we have seen, the difference is mainly in the duration of acceleration, which varies depending on the type of vehicle, and is already presented in Table 1. Thus, a personal car with an average consumption of 8.13 l per 100 km has a consumption of 21.8 l per 100 km during accelerating. Acceleration to 50 km/h takes 10.4 s during which the car travels 72 m. The average consumption is 0.0000813 l/m, while consumption during acceleration is 0.0002158 l per m. Table 2 shows all collected and calculated data for individual vehicle types, taking into account, of course, the factor of increased consumption, which is equal to 2.65 for all types of vehicles.

Table 2. Fuel consumption by individual types of vehicles
Tabela 2. Zużycie paliwa w podziale na typy pojazdów

Type of vehicle	Average consumption (l/m)	Consumption during acceleration (l/m)
Cars	0.0000813	0.0002158
Light goods vehicles (below 3.5 t)	0.0001120	0.0002968
Medium goods vehicles (3.5–7 t)	0.0001690	0.0004478
Heavy goods vehicles (over 7 t)	0.0002350	0.0006227
Trailer vehicles	0.0003500	0.0009275
Towing vehicle	0.0003500	0.0009275
Buses	0.0002800	0.0007420
Motorcycles	0.0000400	0.0001060

Source: [Kumperščak, Bratina and Jereb 2016].

Map of Mariborska cesta with marked traffic lights

On Figure 1 is a map of our model – Mariborska cesta in Celje – on which research was made. All of 14 traffic lights, which influence results of our research, are marked with black dots and numbers. Number 1 is traffic light on north part of Mariborska cesta at exit from motorway. Our "model" or street is 3,202 m long.

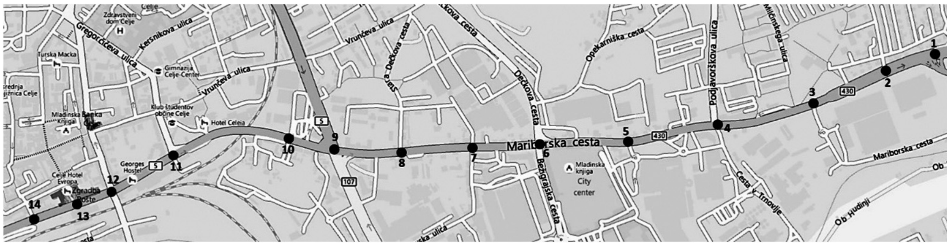

Figure 1. Sketch of the road and marked intersections
Rysunek 1. Szkic badanej trasy i oznaczonych odcinków

Source: Electronic resource https://maps.here.com/?x=ep&map=46.5547,15.6467,10,normal.

Results

End results of fuel consumption

Calculated fuel consumption for one vehicle of every category, was multiplied with a number of vehicles per day (for the same category). This number was then multiplied with a number of days in one year (365 days) and we got our end results of fuel consumption in one year at different traffic regimes or scenarios (0–14 stops) for each category individually.

Combined fuel consumption for all categories of vehicles

To calculate combined fuel consumption for all categories of vehicles, we had to add yearly fuel consumptions of all categories and divided them on patrol and diesel. In category of vehicles that run on patrol are cars (57% in Slovenia) and motorcycles, in category of vehicles that run on diesel are cars (42.2% in Slovenia), buses and all categories of trucks [Statistični urad Republike Slovenije 2016].

Figure 2 shows end results of calculated fuel consumption in one year for Mariborska cesta in Celje. All categories of vehicles are included in calculations and they are split according to fuel type (patrol or diesel). Increasing of fuel consumption with every additional stop is visible on this graph (Fig. 2). The largest combined fuel consumption is at 14 stops and the smallest is at green wave or 0 stops. It is also substantially larger for diesel, because all categories, except motorcycles and 57% of cars, run on diesel fuel.

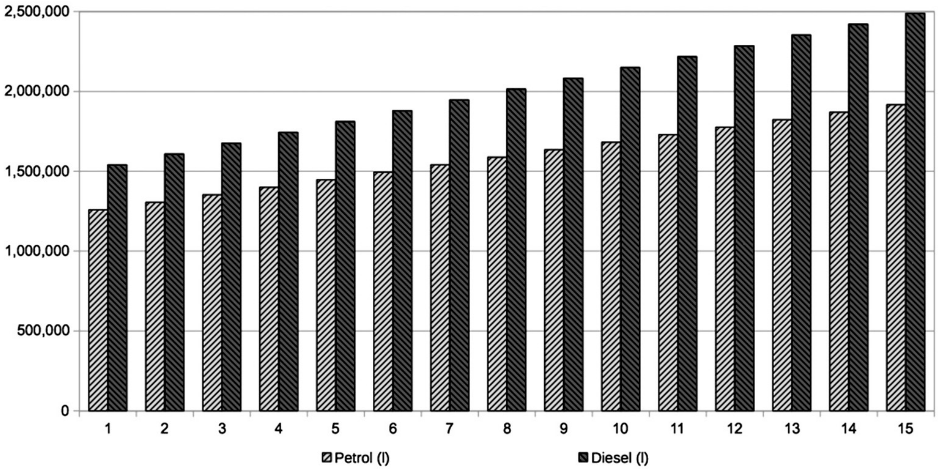

Figure 2. Total fuel consumption of all vehicles in one year

Rysunek 2. Całkowite zużycie paliwa wszystkich typów pojazdów w ciągu roku

Source: [Kumperščak, Bratina and Jereb 2016].

Difference in fuel consumption for all vehicles combined

Difference in fuel consumption for all vehicles combined represents differences between different traffic regimes or situations. Difference between green wave (0 stops) and worse scenarios increases till worse traffic regime (14 stops). Differences in fuel consumption and higher consumption of diesel originates from data showed on Figure 3.

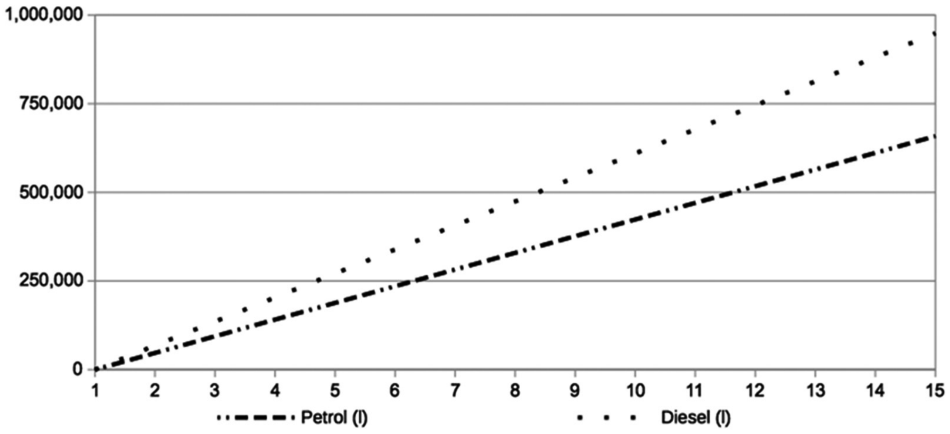

Figure 3. Graphical display of differences in fuel consumption of all vehicles together in one year

Rysunek 3. Graficzne przedstawienie różnic w zużyciu paliwa wszystkich typów pojazdów w ciągu roku

Source: [Kumperščak, Bratina and Jereb 2016].

Average share of different types of vehicles in one day

Figure 4 shows average share or average number of different categories of vehicles in one day for year 2014. Data is from Slovenian infrastructure agency [Štetje 2014].

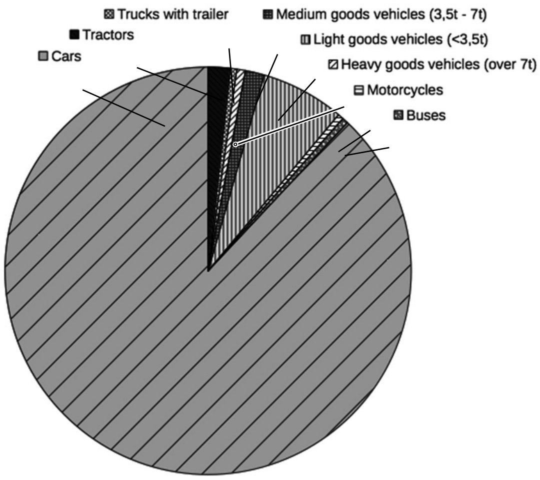

Figure 4. The average number of vehicles per day

Rysunek 4. Średnia liczba pojazdów w podziale na typy na dzień

Source: [Kumperščak, Bratina and Jereb 2016].

Discussion

It can be seen from the research that the flow of road traffic has an unexpectedly big impact on fuel consumption, and consequently also on the amount of PM_{10} particles. In the case of the Mariborska road in Celje, with 14 traffic lights at a distance of 3.2 km and thus 14 possible arrangements for travel on the route, it can be concluded that, at best, 2.8 million l of fuel are consumed and, at worst 4.4 million l. The difference is 1.6 million l of fuel, which at the price of 1.2 EUR per l represents about 2 million EUR. This is a direct saving of money, although it relates only to fuel consumption. Of course, the cost of increased wear on the tires, brakes and damage caused by general jolts of powertrain of the car as a result of starting and braking should also be considered.

In addition to the direct costs due to increased fuel consumption, we should also take into consideration pollution, which manifests itself in an increase of noise and significant release of CO_2 and PM_{10} (includes also $PM_{2.5}$ and PM_1) particles. A study on the increase in pollution due to increased CO_2 emissions and PM particles during acceleration will be carried out next year. The study will take into account the data from this study and the latest findings from the relevant literature. In doing so we distinguish between “gray” and “black” PM particles, and those PM particles which arise from braking. It is characteristic of gray particles that they spread in the atmosphere fairly evenly and extend far from their origin. Black particles are primarily derived from combustion of fuels in internal combustion engines and remain close to the place of origin (the road); as regards PM particles generated as a by-product of braking, we know for sure they are particularly dangerous to health due to their composition.

The study on the increase in pollution is the ultimate goal of our research, as on the basis of relatively short sections of the roads for which we have data on the structure and the number of vehicles, we can generalize the results of the increase in pollution to the whole city, under different fluidity policies of traffic flow conditions in the city.

References

European Comission, 2014: Transmited by PMP Chair. Particle Emissions from Tyre and Brake Wear on-going Literature review Summary and Open Question [electronic resource], 68th GRPE, 7–10.01.2014, agenda item 7, https://www.unece.org/fileadmin/DAM/trans/doc/2014/wp29grpe/GRPE-68-20.pdf [accessed 27.04.2016].

Gasser M., Riediker M., Mueller L., Perrenoud A., Blank F., Gehr P., et al., 2009: Toxic effects of brake wear particles on epithelial lung cells in vitro. Part Fibre Toxicol [electronic resource], http://particleandfibretoxicology.biomedcentral.com/articles/10.1186/1743-8977-6-30 [accessed 27.04.2016].

IVZ RS, ARSO, 2014: Kakovost zraka – zdravje [electronic resource]. Delovna skupina CEHAP, http://www.nijz.si/sites/www.nijz.si/files/uploaded/kakovost_zraka_-_zdravje_peter_otorepec.pdf [accessed 20.04.2016].

Izpusti onesnaževal zraka iz prometa, ARSO, 2014: Kazalci okolja v Sloveniji; 2014 [electronic resource], http://kazalci.arso.gov.si/?data=indicator&ind_id=616 [accessed 22.04.2016].

Kumperščak S., Bratina T., Jereb B., 2016: Zeleni val v prometu, 2014. Poraba goriva na primeru Mariborske ceste v Celju. Celje: Fakulteta za logistiko. Report: DP-29/2016.

Otorepec S., 2015: Model za ocenjevanje tveganj onesnaževanja v cestnem prometu: magistrsko delo [electronic resource], http://dkum.uni-mb.si/Dokument.php?id=80493 [accessed 16.02.2016].

Reduce Air Pollution. Greenpeace East Asia; [electronic resource]. www.greenpeace.org/eastasia/campaigns/air-pollution/.

Research Team Analysis Report. Urban Mobility, 2016, European Commission [electronic resource] http://transport-research.info/sites/default/files/TRIP_Urban_Mobility_brochure-12.04.2016.pdf?utm_source=Ricardo-AEA%20Ltd&utm_medium=email&utm_campaign=6963801_ED60132012/SH/EPEO/TRIP/Brochure&dm_i=DA4%2C459AX%2CJGAWJZ%2CF2OCM%2C1.

Statistični urad Republike Slovenije, 2015: Osebni avtomobili, avtobusi in tovorna vozila in prve registracije teh vozil glede na gorivo, Slovenija, letn [electronic resource], http://pxweb.stat.si/pxweb/Dialog/varval.asp?ma=2222109S&ti=&path=../Database/Ekonomsko/22_transport/08_22221_reg_cestna_vozila/&lang=2 [accessed 16.02.2016].

STA AF. V Ljubljano dnevno 112 tisoč delovnih migrantov, 2015 [electronic resource], http://avto.finance.si/8821313/V-Ljubljano-dnevno-112-tiso%C4%8D-delovnih-migrantov?cookietime=1430637435 [accessed 16.02.2016].

Štetje, 2014: Direkcija RS za infrastrukturo [electronic resource] http://www.di.gov.si/fileadmin/di.gov.si/pageuploads/Prometni_podatki/Stetje_2014.pdf [accessed 16.02.2016].

Correspondence address:
assoc. prof. dr. **Borut Jereb**
University of Maribor
Faculty of Logistics
Mariborska street 7
3000 Celje
CISA, CISM, CGEIT
Borut.Jereb@um.si

Samo Kumperščak
University of Maribor
Faculty of Logistics
Mariborska street 7
3000 Celje
samo.kumperscak@student.um.si

Tadej Bratina
University of Maribor
Faculty of Logistics
Mariborska street 7
3000 Celje
tadej.bratina@student.um.si